Trapezial Topography in Thumb Carpometacarpal Arthritis

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Abstract

Objective Contradictory reported arthritic patterns of the metacarpal surface of the trapezium include preferential volar wear, radial wear, and dorsal-ulnar sparing. We investigated whether a predominant wear pattern exists in surgical trapeziectomy for advanced thumb carpometacarpal (CMC) arthritis.

Methods We examined 36 intact trapezia from 34 thumb CMC arthroplasty patients over an 18-month period. The first metacarpal articular surface revealed three consistent morphology patterns: (1) saddle, (2) dish, and (3) cirque. The saddle represented cartilage loss with preservation of the normal trapezial morphology. The dish shape represented concave curvature, with loss of the normal saddle configuration. The cirque shape represented preferential volar concave wear, disrupting the convex volardorsal arc. Two surgeons classified the randomized specimens twice, blinded to patient identity and each other's categorization. Radiographic Eaton staging was correlated retrospectively for 35 of 36 of the trapezial specimens. Eight specimens were further quantified with micro-computed tomography (micro-CT).

Results Thirty-six trapezia were classified as follows: 17 (47%) saddle, 12 (33%) dish, and 7 (19%) cirque. Intra-rater reliability was 0.97 and 0.95; inter-rater reliability in the second round was 0.95. The 36 trapezia represented 27 female (75%) and 9 male (25%) patients; 18 (50%) represented the dominant hand. Age at surgery averaged 64 (33–76). Complete cartilage loss of the entire metacarpal surface was seen in 15 (42%) of all specimens. Osteophyte presence was typically minimal in the saddle group; the dish group had characteristic extensive rimming osteophytes in a 91% female population (11/12), and the cirque group had volar osteophytes. Radiographic severity ranged from Eaton stage II to IV; less severe radiographic staging (Eaton II) predominated in the saddle configuration; advanced Eaton III–IV disease predominated in both cirque and dish shapes. Micro-CT verified the three discrete shapes with volardorsal and radioulnar orientation measurements.

Conclusion The metacarpal surface of the trapezium demonstrates three distinct patterns of wear in arthritic surgical specimens. Sex, dominance, age distribution, and Eaton stage varied across the different shapes.

Level of Evidence Level 3

Study Type Observational

Keywords

- Trapezium
- CMC arthritis
- abnormal loading
- bone morphology

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Thumb carpometacarpal (CMC) arthritis affects one in four women in the United States over age 55 as well as a significant number of men.[1] The precision, power, and mobility demanded from the thumb to perform simple yet vital tasks such as pinch and grasp makes thumb CMC arthritis particularly debilitating. The human trapezium is described as "saddle shaped" or bi-concave-convex; the saddle is concave in the radioulnar axis and convex in the volardorsal axis[2,3] (►**Fig. 1a,b**). The human trapezium evolved from a simple congruent saddle in early hominins to the complex loose saddle in modern humans to meet the demands of stability, mobility, and strength required for dexterity and power.[4–7] Studies of congruency and cartilage wear in thumb CMC arthritis report contradictory etiology and patterns of wear.[8–10]

Pellegrini described preferential volar "eburnation" (complete loss of cartilage with exposed polished subchondral bone) in arthritic trapezia, concluding the cause to be degeneration of the volar beak ligament.[8] Nufer and colleagues found preferential radial wear,[9] while the Strauch and Rosenwasser group documented relative sparing of the dorsal-ulnar quarter of the trapezium,[10] thus in partial agreement with both Pellegrini and Nufer.[8,9] The authors[10] noted that these wear patterns were largely sex specific, concluding that female subjects developed a volar wear pattern because of degeneration of the volar beak ligament, whereas male subjects developed a dorsoradial wear pattern due to pinch forces.

Lack of significant remodeling of the metacarpal in advanced thumb arthritis is supported in previous studies. The Strauch and Rosenwasser group quantitatively examined the topography of 46 trapezia and metacarpal pairs, finding that "the metacarpal cartilage and subchondral bone surfaces do not remodel significantly with age and OA—all of the changes occur in the trapezium."[10] Pellegrini found "the absolute and fractional areas of each surface eburnated and worn to subchondral bone were consistently greater on the trapezium than on the metacarpal" in a ratio of ~3:1.[8] In the senior author's experience of routine trapeziectomy, metacarpal cartilage wear is variable but rarely includes morphologic changes, and thus the first metacarpal morphology is not a focus of this study.

We have observed three different wear patterns from surgically removed intact trapezia, ranging from a preserved saddle shape (►**Fig. 2a,b**) to a reversal of the volardorsal convex shape into a concave "dish" with extensive rimming osteophytes (►**Fig. 3a,b**). Occasionally trapezia demonstrate a preferential volar wear pattern, creating a separate concave facet that disrupts the usual volardorsal convexity. This resembles a geological "cirque," a bowl-shaped depression found at a mountaintop as a result of glacial erosion (►**Fig. 4a,b**). The observed wear patterns suggest the osteoarthritis may progress from the saddle configuration to a cirque pattern and then a dish (►**Fig. 3a,b**); or, alternatively, two distinct wear processes progress to either a cirque or a dish. Thus, we hypothesize that distinct patterns of visible trapezial wear exist. We furthermore hypothesize that these patterns correlate with demographic information, radiographs, and comparative micro-computed tomography (micro-CT).

Materials and Methods

The senior author excised 40 intact trapezia from 38 patients who underwent thumb arthroplasty for osteoarthritis, radiographic Eaton stage II–IV disease,[3,11] over an 18-month period. Four trapezia were excluded; one trapezium was fractured on removal, and three were sectioned for histology prior to evaluation. This left 27 female (75%) and 9 male (25%) specimens for examination. Average age at surgery was 64 (33–76). The youngest subject was a 33 -year old female postal worker with idiopathic bilateral thumb CMC arthritis. The trapezia constituted 21 right and 15 left, including 48% (17/36) from the dominant hand. Occupation was known for 28 of the 34 patients, including homemaker (8), receptionist (4), postal worker (2), and school aide (2). Other occupations included surgeon, librarian, dental hygienist, artist, yoga instructor, firefighter, waitress, athletic director, and security guard.

The surgical technique entails excising the trapezium via a Wagner incision centered over the thumb CMC joint, developing the interval between the thenar muscles and the

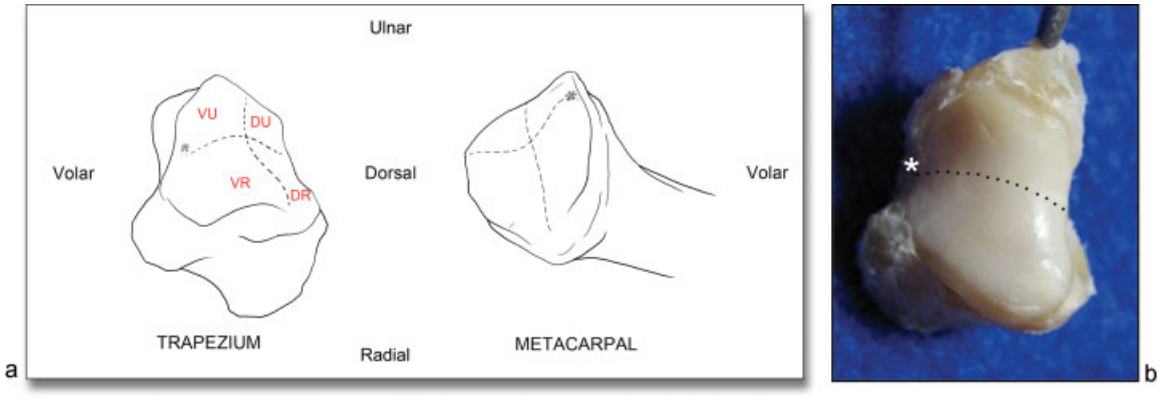

Fig. 1 (**a**) The normal topography of a right trapezium and and articulating surface of the metacarpal. The quadrant depictions are modified from Atheshian.[3] The (*) represents the volar beak of the metacarpal and its articulating recess on the trapezium. (**b**) A normal right trapezium. The pin is fixed in the dorsal ulnar tubercle, and the (*) represents the articulating recess for the metacarpal beak. The dotted line represents the convex curvature of the volardorsal axis and bisects the ulnar and radial halves.

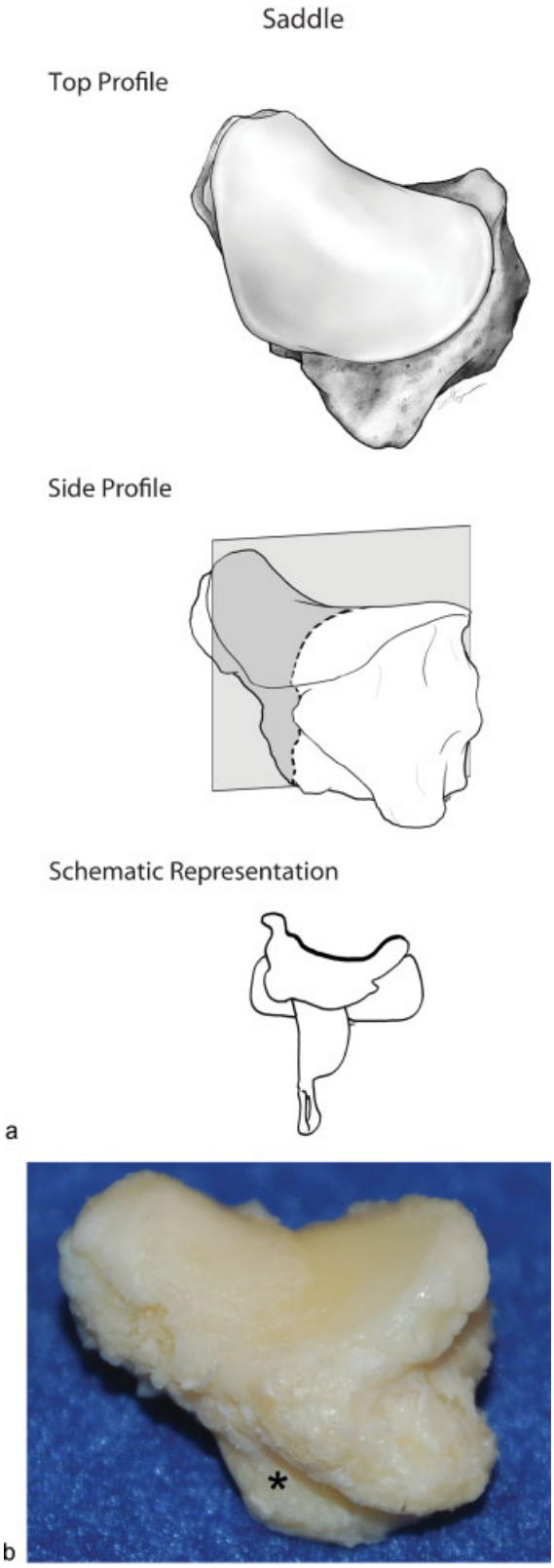

Fig. 2 (a) A schematic of the retained saddle configuration of the right trapezium. (b) A surgical specimen of a retained saddle, right trapezium. The radial half demonstrates articular wear. The trapezium lacks substantial rimming osteophytes. The (*) represents the flexor carpi radialis groove.

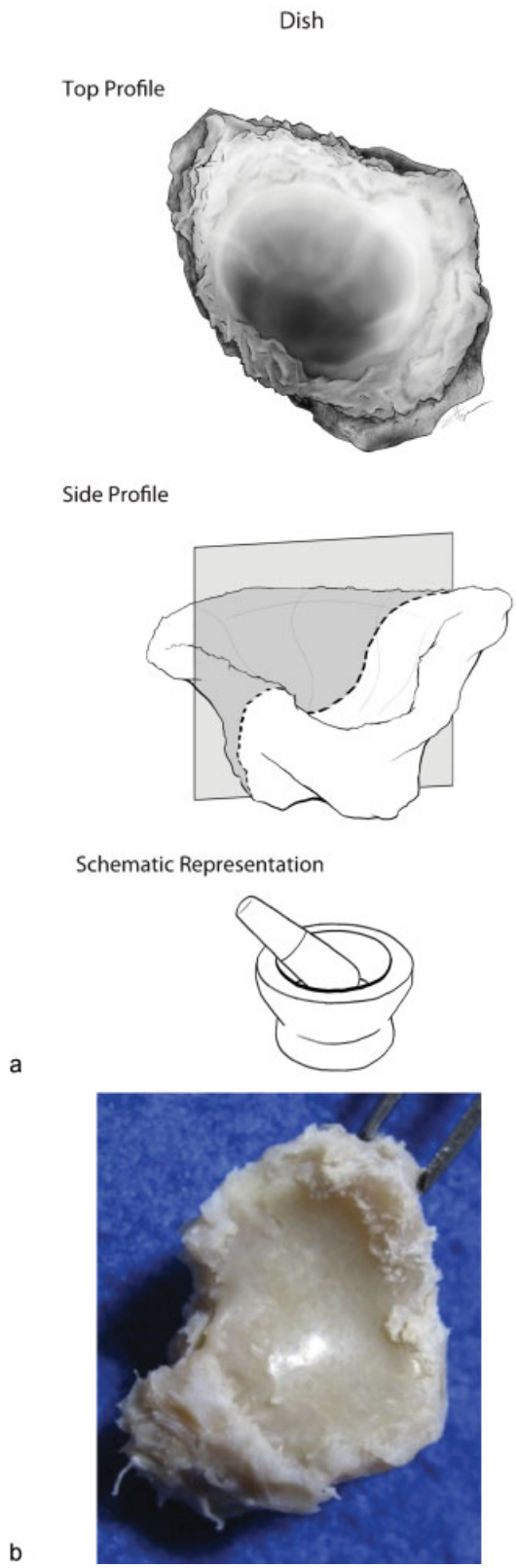

Fig. 3 (a) A schematic of the concave dish configuration of the right trapezium. (b) A surgical specimen of a dish-shaped right trapezium. The forceps is positioned on the dorsal ulnar tubercle. Substantial rimming osteophytes accompany the neo-concave shape.

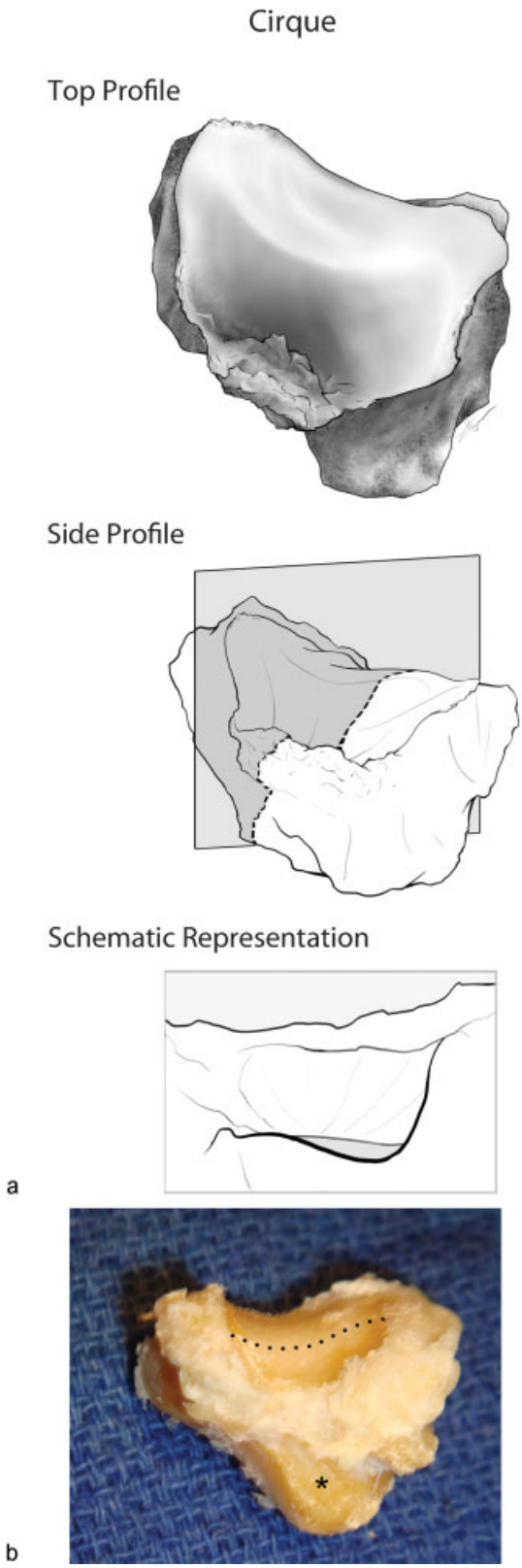

Fig. 4 (**a**) A schematic of the cirque configuration of the right trapezium. (**b**) A surgical specimen of a cirque-shaped right trapezium. The dotted line represents the radioulnar demarcation of volar concavity and dorsal convexity. The (*) represents the flexor carpi radialis groove.

abductor pollicis longus (APL), usually dividing an accessory APL slip to the abductor pollicis brevis. The trapezium is dissected free of investing ligaments circumferentially with the aid of a 3.5 tap as a joystick passed parallel to the scaphotrapezial joint in the direction of the second metacarpal. The flexor carpi radialis is protected within its oblique groove. The investing ligaments, in order of tenacity, include the attachment of the transverse carpal ligament just ulnar to the FCR groove; the dorsal ligaments; and the intermetacarpal ligament.

Two surgeons visually and manually inspected the wear patterns of each specimen. We observed three types of wear morphology consistent with previous observations: (1) *saddle* shape, (2) *dish* shape, and (3) *cirque* shape (►**Figs. 2–4**). No additional patterns were observed. After randomization, each specimen was reclassified twice, with each examiner blinded to patient identity and the other examiner's categorization. Extent of cartilage wear[12] including eburnation (full cartilage loss and exposed, polished subchondral bone[8] and percentage of the trapezial articular surfaces (first metacarpal base, scaphoid, trapezoid, and second metacarpal), preferential wear patterns, and osteophyte locations were documented.

Hand radiographs for each subject were classified retrospectively by two of the authors (ALL and AJB) and subsequently compared with the shape.

We further analyzed the distal articular (first metacarpal) contour in 8 trapezia using micro-CT (vivaCT 40, Scanco Medical AG, Wayne, PA) applying volumetric surface rendering software (Amira, Visage Imaging, San Diego, CA) to orient and measure the scanned image of each specimen. Representative specimens included three saddle, three dish, and two cirque trapezia, which were correlated to gross observations. The maximum volardorsal and radioulnar dimensions of each trapezium were measured from volumetric surface renderings. Three computational cutting planes were made in the volardorsal axis: first at the midpoint and subsequently bisecting these at the 1/4 (dorsal) and 3/4 (volar) position of the overall length. Subsequently, the process was repeated in the radial-ulnar plane. This created six 2D slice representations for each trapezium.

Approval for this project was granted through the investigational review board, and the handling of human remains adhered to ethical and clinical protocols.

Results

The 36 classified trapezial specimens from 34 patients followed three patterns: 17 (46%) saddle, 12 (33%) dish, and 7 (19%) cirque (►**Figs. 2–4**). Complete loss of cartilage with eburnation[8] and Outerbridge grade 4[12] of the entire distal articular trapezial surface was found in 15 trapezia (42%). The arthritic saddle shape represented presence of eburnated bone in selected areas with preservation of the normal trapezial morphology. The dish shape represented concave curvature with central eburnation, losing the normal saddle configuration. The cirque shape represented preferential volar concave eburnation, disrupting the convex volardorsal

arc. Intra-rater reliability was 0.97 and 0.95. The inter-rater reliability of the second round of classification was 0.95.

Retrospective review of the subject's radiographs was performed independently and then jointly by two of the authors (ALL and AJB). The Eaton staging includes subluxation as a part of its staging criteria, and we interpreted this requirement differently.[3,11] Recent literature suggests that subluxation is physiologically normal[13,14]; thus, we reinterpreted radiographs by consensus, eliminating subluxation as a requirement for severity staging. The shapes were compared with Eaton staging (►**Table 1**).

Saddle

The 17 saddle specimens (►**Fig. 2**) had a preserved convexity in the volardorsal plane and concavity in the radioulnar plane. The male specimens preferentially represented the saddle shape (6/9), notable since male specimens constitute 25% (9/36) of the total population. The saddle group uniquely had more nondominant (58%) than dominant (42%) hand specimens, a number too small for statistical comparison. The average age was 62 (range 33–76); the 33-year old female subject possessed a saddle shape.

The most common wear pattern within the saddle morphology specimens (nine trapezia, 53%) was preferential radial and volar cartilage eburnation with sparing of the dorsal ulnar corner of the first metacarpal articulation, similar to Pellegrini's observation of Eaton stage III osteoarthritis.[8] Radial wear was more common than ulnar wear: twelve specimens with saddle morphology (67%) demonstrated preferential radial wear, one (3%) demonstrated preferential ulnar wear, and four (11%) did not exhibit preferential radial or ulnar wear. Similarly, five specimens had solely radial osteophytes versus one with a single ulnar osteophyte. Volar wear was more common than dorsal wear: eleven total saddle specimens (65%) had preferential volar wear, versus two (11%) with preferential dorsal wear. Four specimens (22%) had equivalent volar and dorsal wear and exhibited diffuse circumferential osteophytes.

The percentage of cartilage loss of the entire metacarpal surface ranged from 25% to 100% based on gross observation, absent of staining techniques or histology. A majority (10/17) had involvement of 50–70% of the first metacarpal articular surface. Only 3 of 17 specimens had complete wear of the entire first metacarpal articulation.

All articular facets of the trapezium were examined including the scaphoid, trapezoid, and second metacarpal articulations. Trapezoid and second metacarpal wear was more common (7, 41%) than scaphoid wear (4, 23%).

The saddle-shaped specimens had the least severe radiographic staging: nine with Eaton II, three with Eaton III, and five with Eaton IV, involving additional wear of other articulations of variable degree (►**Table 1**). Incomplete wear seen on other facets of the trapezium during gross examination did not correspond to radiographic involvement (Eaton IV). Representative micro-CT slices in the volardorsal and radioulnar orientations illustrate preservation of convexity in the volardorsal plane and concavity in the radioulnar plane (►**Fig. 5a,b**).

Table 1 Trapezial morphology compared with radiograph (Eaton staging)

Saddle (17 specimens)
Eaton II: 9 (53%)
Eaton III: –3
Eaton IV[a]: 5
Dish (12 specimens)
Eaton II: –1
Eaton III: –5
Eaton IV: –5
No radiography available: 1
Cirque (7 specimens)
Eaton III: –5
Eaton IV: –2

[a]2 specimens (same subject, left and right trapezia) had CMC joint narrowing, minimal osteophytes consistent with Eaton stage II, with involvement of scaphotrapezial joint.

Dish

One-third (12/36) of the specimens possessed a dish morphology (►**Fig. 3**). All but one dish (11/12) came from female patients; the sole male patient was a yoga practitioner. The average age was 64 with a range of 50–76 years; 50% (6/12) were from the dominant hand.

All dish specimens had eburnation of the entire distal trapezial articular surface with extensive circumferential rimming osteophytes. The concavity depth was variable, but the deeper dishes had more diffuse cartilage wear of varying degrees involving the scaphoid, trapezoid, and second metacarpal articulations. The dish shape consistently possessed more severe Eaton staging (III–IV; ►**Table 1**), with corresponding grossly appreciable scaphoid, trapezial, and second metacarpal wear in 58% of specimens. Thirty-three percent of specimens[5] had broad scaphoid facets.

Representative micro-CT slices in the volardorsal and radioulnar orientations illustrate the dish morphology (►**Fig. 6a,b**).

Cirque

Seven (19%) of the specimens had a cirque shape (►**Fig. 3**). They consistently demonstrated a concave volar slope; some with a sharp demarcation similar to a volar facet, and all with variably sized volar osteophytes creating a ledge at the metacarpal beak articulation. Eighty-six percent (6/7) were from female patients; the sole male patient was a surgeon. Seventy-one percent (5/7) represented the patient's dominant hand. The average age of cirque specimens was 66 (range 50–76) years.

The cirque specimens showed little to no scaphoid and trapezoidal wear. Three specimens had complete eburnation of the second metacarpal articulation with absent scaphoid and trapezoid changes. This was not reflected in their Eaton staging (III). The two Eaton stage IV specimens had

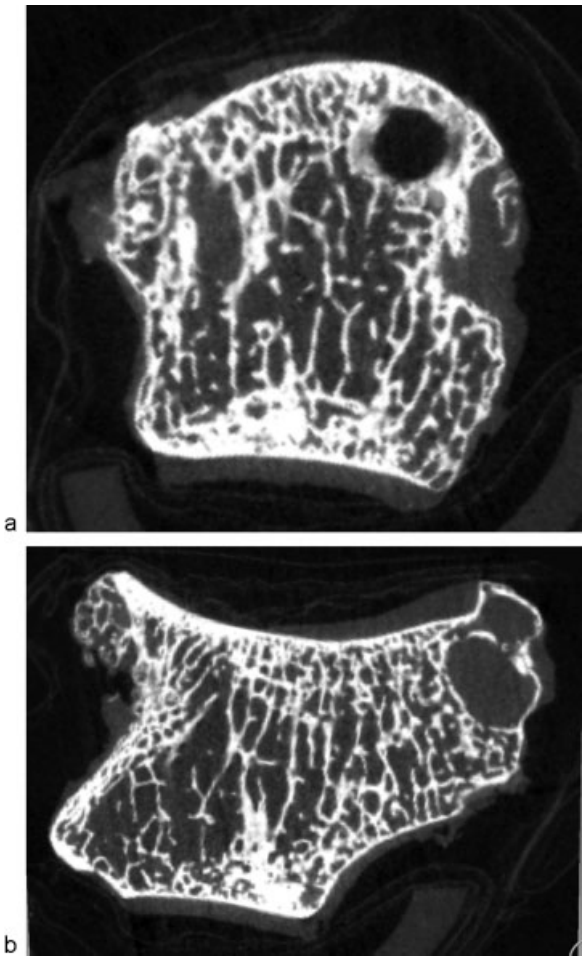

Fig. 5 Micro-CT demonstrates the retained saddle shape: convex in the dorsoradial plane (**a**) and concave in the radioulnar plane (**b**). The dark circle in (**a**) is artifact from the drill pathway of a tap inserted to aid removal. The gray circle in (**b**) represents degenerative cysts.

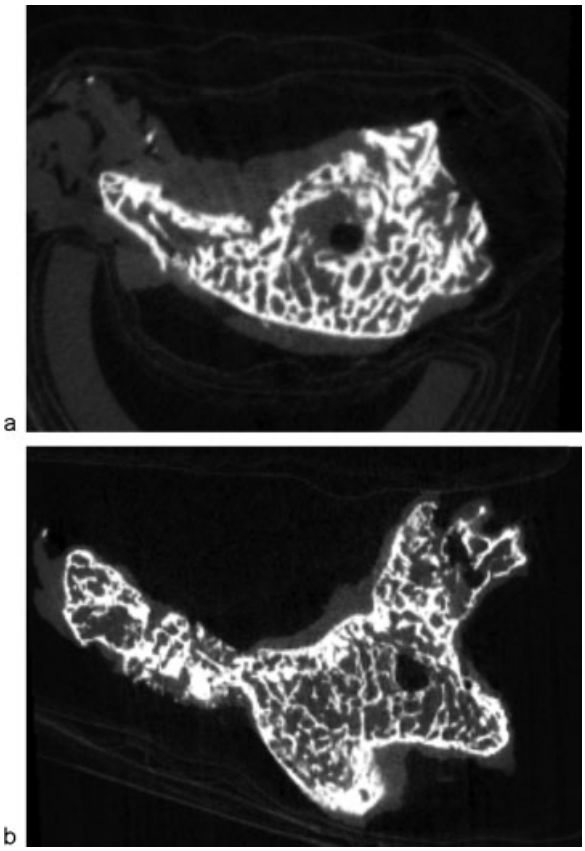

Fig. 6 Micro-CT demonstrates the dish shape: concave in both planes. The dark circle in (**a**) is artifact from the drill pathway of a Kirschner wire inserted to aid removal.

radiographic joint space narrowing but no erosive changes or osteophytes (►**Table 1**). Representative micro-CT slices in the volardorsal and radioulnar orientations illustrate the cirque wear pattern (►**Fig. 7a,b**), demonstrating the partial reversal of the convexity in the volardorsal plane.

Discussion

Our observations of wear patterns complement other investigations that implicate bone morphology and joint loading as contributors to the etiology of thumb CMC osteoarthritis. High inter-rater and intra-rater reliability supports our hypothesis that distinct patterns of distal trapezial wear exist. We propose that the disparate wear patterns identified represent divergent wear, rather than a continuum of disease progression. The physiologic normal saddle shape may progress solely to an arthritic saddle as an end-stage pattern or progress to either concentric wear (dish) or eccentric wear (cirque). Alternatively, a normal physiologic saddle may progress to a cirque pattern and subsequently to a dish. Less severe radiographic staging generally compared with the arthritic saddle shape in our study. Without longitudinal studies, it is unclear whether an arthritic but preserved saddle shape corresponds to "early" disease that progresses to more advanced disease such as a cirque or dish shape, or, alternatively, the arthritic saddle represents a different form of end-stage disease that does not correlate to radiographic severity as currently measured with the Eaton staging system. Clinical symptoms often do not correspond to radiographic disease. This concept potentially supports distinct patterns of arthritis development that do not correspond to currently available systems of radiographic severity staging.

Our findings possibly unify contradictory observed wear patterns in previous reports.[8–10] Specimen population and examination methodologies differed across these studies. Xu's direct inspection of cadaveric trapezia with at least minor cartilage defects demonstrated relative dorsoulnar sparing. Direct inspection and methylene blue staining of hyaline cartilage revealed preferential volar wear in Pellegrini's surgical population of 27 trapezia with advanced, Eaton stage III/IV disease.[8] Our saddle and cirque patterns concur with Xu's and Pellegrini's findings, respectively. The saddle shape with preferential volar radial wear concurs with Nufer's 15 surgical specimens of advanced arthritis measured with micro-CT.[9] They examined subchondral and trabecular bone volume, density, and structure in radial, middle, and ulnar columns of the trapezium, intentionally eliminating the volar and dorsal 30% of the articular surface and osteophytes

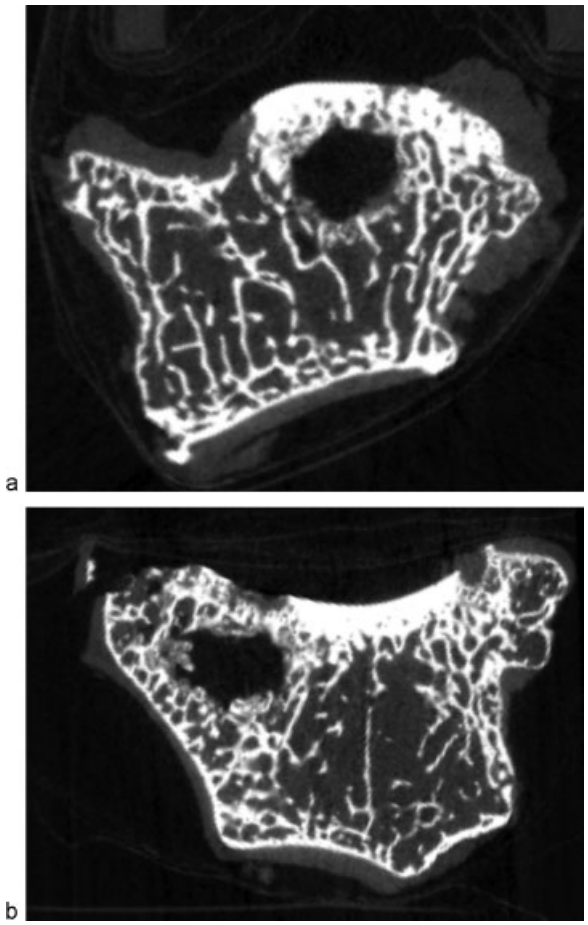

Fig. 7 Micro-CT demonstrates the cirque shape: concave in the volar half, and concave in the dorsal half of the volardorsal plane (**a**). The concavity is preserved in the radioulnar plane (**b**). The dark circle in both images is artifact from the drill pathway of a tap inserted to aid removal.

from analysis for comparative consistency. We believe, however, that this elimination excludes analysis of critical bone areas. Our own micro-CT investigation of 16 arthritic and 13 normal CMC joints, which included the metacarpal and trapezial articular surface and adjacent osteophytes, demonstrates a volume increase in both normal and arthritic trapezia in the volar ulnar portion.[15] These findings support the preferential volar loading concept of both Pellegrini and Xu.[8,10]

We propose that the cirque specimens represent concentrated volar contact from the metacarpal beak of the dorsally subluxated metacarpal, similar to Pellegrini's concept of preferential volar arthritis expanding "centrifugally" in Eaton stage III and IV specimens.[8] Further micro-CT analysis of trabecular bone and surface morphology in additional cirque specimens, as well as CT kinematic analysis, will be required to support this proposed theory.

The concave dish specimens had the highest incidence of arthritic scaphoid and trapezoid facets and radiographic severity. A third of these had notable broad scaphoid facets, suggesting that facet size variation may contribute to degeneration. North and Eaton showed that radiographic disease most commonly affects the trapezial–first metacarpal and scaphotrapezial joints but typically spares the trapezium–trapezoid and trapezium–second metacarpal joints,[16,17] and they believed that "pantrapezial arthritis" was a misleading term. Yet, we found involvement of scaphoid, trapezoid, and second metacarpal facets across the three types of wear patterns. Further imaging and biomechanical data will be required to address the variability of the entire trapezial shape and arthritic wear patterns.

There are additional limitations to this descriptive study. The cross-sectional evaluation at time of surgery is not a longitudinal study, and thus we can only postulate that unique patterns of load determine disease shape. A continuum of disease progression, thus, cannot be excluded. Since the matching wear patterns on the base of the thumb metacarpal were not explanted and examined with the trapezia, we can draw limited conclusions regarding paired wear patterns. Similarly, wear patterns and eburnation are visual descriptions of complete cartilage loss; histological staining was not performed to quantify loss from thinning to complete wear. Although representative of the surgical population, disproportionate numbers of male and female trapezia (9 vs. 27) were examined in this study. Our small sample size supports the suggestion that men demonstrate different wear patterns than women. Pellegrini is the only other CMC topographical author to utilize specimens from patients with symptomatic disease rather than cadavers, but he makes no mention of the sex of his subjects nor sex-specific wear patterns.[8] Normal anatomic variants of the trapezium may predispose wear patterns; to date, little is known about normal variation in trapezial shape to address this topic.

Our limitations present opportunities in the next phase of investigation. We have found in preliminary studies that asymptomatic subjects (12 female, average age 39; 12 male, average age 42), regardless of sex, did not demonstrate statistically different morphology patterns of both the first metacarpal and trapezial surfaces.[18] Nor did the same subjects demonstrate statistically different loading patterns when performing clinical tasks of key pinch, grasp, and jar opening.[19] This suggests that morphology and functional load patterns are not sole contributors to arthritis development; abnormal load and degeneration may additionally require a combination of factors such as genetics, aging, and impaired neuromuscular control. Future investigation of causative factors will expand available information for tailoring treatment and improve prevention of this common form of osteoarthritis.

Note

All work was conducted at the Robert A. Chase Hand Center, Stanford University, Palo Alto, CA.

Ethical Review Committee Statement

IRB approved by Stanford University, titled "Investigation of Biochemical and Histological Properties in Upper Extremity Pathology."

Conflicts of Interest
One or more of the authors (AL Ladd) has received funding from the Williams Charitable Trust, NIH (SBIR) / NBIB R43 EB003067–02A1; OREF/DePuy/RJOS Career Development Award.
All other authors have no conflicts of interest

References

1 Armstrong AL, Hunter JB, Davis TR. The prevalence of degenerative arthritis of the base of the thumb in post-menopausal women. J Hand Surg [Br] 1994;19(3):340–341
2 Gray H, Lewis WH, ed. Anatomy of the Human Body. 20th ed. Philadelphia, PA: Lea & Febiger; 1918
3 Eaton RG, Glickel SZ. Trapeziometacarpal osteoarthritis. Staging as a rationale for treatment. Hand Clin 1987;3(4):455–471
4 Marzke MW, Tocheri MW, Steinberg B, et al. Comparative 3D quantitative analyses of trapeziometacarpal joint surface curvatures among living catarrhines and fossil hominins. Am J Phys Anthropol 2010;141(1):38–51
5 Tocheri MW, Razdan A, Williams RC, Marzke MW. A 3D quantitative comparison of trapezium and trapezoid relative articular and nonarticular surface areas in modern humans and great apes. J Hum Evol 2005;49(5):570–586
6 Tocheri MW, Orr CM, Jacofsky MC, Marzke MW. The evolutionary history of the hominin hand since the last common ancestor of *Pan* and *Homo*. J Anat 2008;212(4):544–562
7 Tocheri MW, Marzke MW, Liu D, et al. Functional capabilities of modern and fossil hominid hands: three-dimensional analysis of trapezia. Am J Phys Anthropol 2003;122(2):101–112
8 Pellegrini VD Jr. Osteoarthritis of the trapeziometacarpal joint: the pathophysiology of articular cartilage degeneration. II. Articular wear patterns in the osteoarthritic joint. J Hand Surg Am 1991;16(6):975–982
9 Nufer P, Goldhahn J, Kohler T, Kuhn V, Müller R, Herren DB. Microstructural adaptation in trapezial bone due to subluxation of the thumb. J Orthop Res 2008;26(2):208–216
10 Xu L, Strauch RJ, Ateshian GA, Pawluk RJ, Mow VC, Rosenwasser MP. Topography of the osteoarthritic thumb carpometacarpal joint and its variations with regard to gender, age, site, and osteoarthritic stage. J Hand Surg Am 1998;23(3):454–464
11 Eaton RG, Littler JW. Ligament reconstruction for the painful thumb carpometacarpal joint. J Bone Joint Surg Am 1973;55(8):1655–1666
12 Outerbridge RE. The etiology of chondromalacia patellae. J Bone Joint Surg Br 1961;43-B:752–757
13 Wolf JM, Oren TW, Ferguson B, Williams A, Petersen B. The carpometacarpal stress view radiograph in the evaluation of trapeziometacarpal joint laxity. J Hand Surg Am 2009;34(8):1402–1406
14 de Raedt S, Stilling M, van de Giessen M, Streekstra GJ, Vos FM, Hansen TB. A three-dimensional analysis of osteoarthritic changes in the thumb carpometacarpal joint. J Hand Surg Eur Vol 2012; [Epub ahead of print]
15 Lee AT, Williams AA, Lee J, Cheng R, Lindsey DP, Ladd AL. Trapezium Trabecular Morphology in Carpometacarpal Arthritis. J Hand Surg Am 2013;38(2):309–315
16 Eaton RG. Replacement of the trapezium for arthritis of the basal articulations: a new technique with stabilization by tenodesis. J Bone Joint Surg Am 1979;61(1):76–82
17 North ER, Eaton RG. Degenerative joint disease of the trapezium: a comparative radiographic and anatomic study. J Hand Surg Am 1983;8(2):160–166
18 Halilaj E, Rainbow MJ, Got C, Schwartz JB, Moore DC, Weiss AP, Ladd AL, Crisco JJ. In vivo kinematics of the thumb carpometacarpal joint during three isometric functional tasks. Clin Orthop Relat Res 2013 May 17. [Epub ahead of print] PubMed PMID: 23681597.
19 Ladd AL, Weiss AP, Crisco JJ, et al. The thumb carpometacarpal joint: anatomy, hormones, and biomechanics. Instr Course Lect 2013;62:165–179